Defining "Cognition": Cognitive Ontology via Text-Mining and Word-Embedding

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Defining Cognitive Processes

Cognitive Neuroscience aims to find the neural substrate of mental processes. How do we define these theoretical mental constructs precisely when they are often described in words and in relation to each other?

Question 1: What is the ontological structure of cognitive processes?

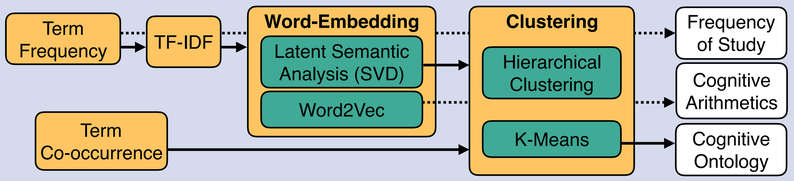
- Cognitive processes are not stand-alone operations in the mind. Can we map out how they are related to each other by how scientists talk about them?
- (related works: **Cognitive Atlas, Neurosynth**)

Question 2: Do cognitive theories inform neuroscience & vice versa?

- Cognitive science is rooted in computationalism, which has been an useful but perhaps outdated metaphor for the brain.
- When cognitive scientists & neuroscientists study a cognitive process, are they looking at the same thing, and in similar ways?

Data & Method

- 815 cognitive terms (Concepts) from the Cognitive Atlas are scraped and used as search terms (e.g., "memory", "procedural knowledge", "goal maintenance").
- Cognitive terms were used to seed searches for 4 datasets:
  - **PubMed {Cogs, Neu, NeuMet}**: terms were searched in conjunction with 1 of 3 sets of "base phrases", and the number of abstracts returned were recorded. **e.g.** "attention" AND "memory" AND ("cognitive" OR "cognition")
  - **Cognitive Science**: abstracts from CogSci proceedings (2008-2017) were scraped to construct term-document matrices and term co-occurrence matrices.



Data and code: **github.com/voytekresearch/IdentityCrisis** | **rigao@ucsd.edu** | _rdgao

Key Take-Aways

I. Cognitive processes can be clustered to create ontologies. Cognitive processes are often related to one another (Poldrack & Yarkoni, 2016), and we define them in relation to each other in the literature. This tool can serve as an educational overview or semi-automated curation.

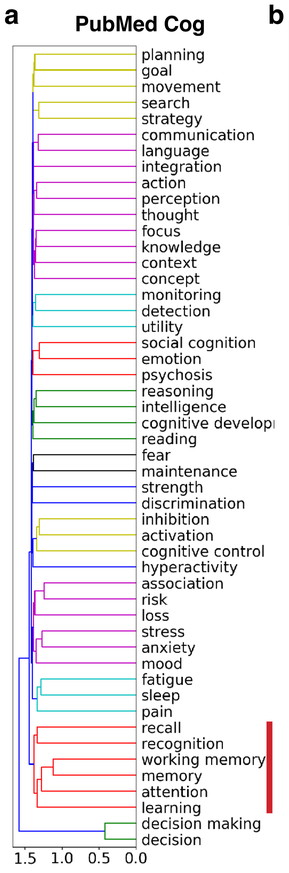
II. Cognitive terms can be added and subtracted to query similarity. Cognitive processes are often intrinsically linked due to the way we use language, which is imprecise. Word embedding decouples concepts by finding a latent semantic space, in which we can explore interactively.

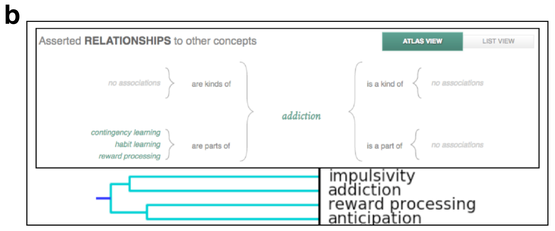
III. Cognitive science & neuroscience - different focus & ontologies. If cognitive theories are to make a broad impact on our investigation of the neural bases of cognitive processes (Frank & Badre, 2015), a convergence of topic and their respective ontology in these literatures should follow.

Main Results

Topic Modeling "Cognition"

Cognitive terms form clusters based on co-occurrence





a. Hierarchical clustering results for PubMed Cogs dataset. Red bar highlights "**learning**".
b. Curation for "**addiction**" in the Cognitive Atlas, compared to the generated ontology.

Hierarchical clustering show automated discovery of sensible relations.

Using term co-occurrence alone (Jacard Index),

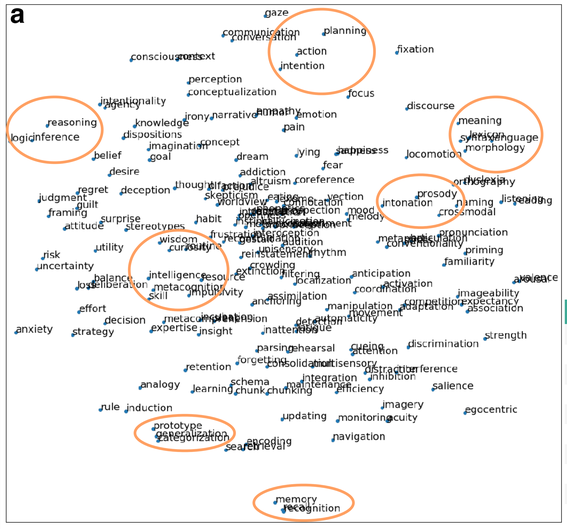
$$J(A,B) = \frac{|A \cap B|}{|A| + |B| - |A \cap B|}$$

hierarchical clustering groups highly related terms together, forming a kind of semantic structure. Qualitatively, we find sensible clusters in each dataset, while dataset-specific differences also exist.

As a whole, these results quickly and broadly survey the literature, serve as a sanity check on how neuroscientists & cognitive scientists study these processes. It can also serve as a hypothesis-generation tool, and reveal field differences in conceptualization of these terms.

Vector Word-Embedding

"representation" - "memory" = ???



b

representation			
+ memory		- memory	
itm	0.800389	concept	0.358402
formation	0.774059	embodied	0.327143
maintenance	0.772139	symbols	0.326573
visual-recognition	0.769506	space	0.313220
templates	0.754242	grounded	0.308997
storing	0.754001	grounding	0.308103
visual-memory	0.752331	representations	0.295357
long-term-memory	0.746364	concrete	0.291695
human's	0.745050	whole	0.289701
vstm	0.744142	meaning	0.287940

c

learning			
+ categorization		- categorization	
category-learning	0.828328	teaching	0.275147
generalization	0.772169	tutoring	0.241622
observational	0.769656	students	0.238550
interleaving	0.760952	learn	0.236814
concept-learning	0.759609	intervention	0.228284
hypothesis-testing	0.751590	middle	0.224874
pl	0.742077	learners	0.224605
semi-supervised	0.734568	students'	0.222236
impose	0.732379	classroom	0.218149
formation	0.729734	writing	0.207617

a. t-SNE projection of Word2Vec word vectors onto 2-dimensions. Circles highlight clusters.
b&c. Most similar words for "representation" ± "memory" (b) and "learning" ± "categorization" (c).

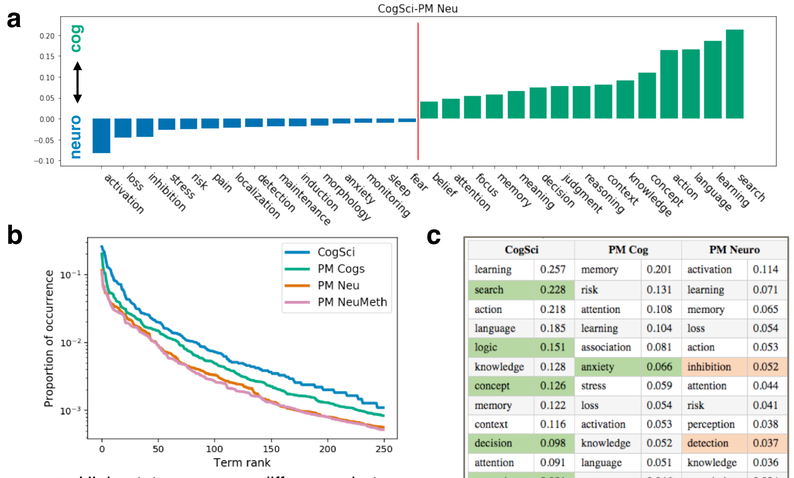
Word2Vec learns latent embedding vectors from abstracts.

Using skip-gram representation, Word2Vec is trained to predict context (flanking words) from a given word in a sentence. Learned word vectors are further projected onto lower dimension via t-SNE for visualization.

From their vector representation, we can perform arithmetics on cognitive processes to ask questions like: "what is representation with and without memory?", based on existing studies.

Focus of Investigation

Discrepancy between computation & implementation



a. Highest term usage difference between CogSci & PubMed Neuro

b. Proportion of occurrence of top 250 terms in each dataset.

c. Top 20 terms in each dataset and their proportion of occurrence. **Green**: unique terms in the top-20 of each dataset; **Red**: neuro only terms.

c

CogSci		PM Cog		PM Neuro	
learning	0.257	memory	0.201	activation	0.114
search	0.228	risk	0.131	learning	0.071
action	0.218	attention	0.108	memory	0.065
language	0.185	learning	0.104	loss	0.054
logic	0.151	association	0.081	action	0.053
knowledge	0.128	anxiety	0.066	inhibition	0.052
concept	0.126	stress	0.059	attention	0.044
memory	0.122	loss	0.054	risk	0.041
context	0.116	activation	0.053	perception	0.038
decision	0.098	knowledge	0.052	detection	0.037
attention	0.091	language	0.051	knowledge	0.036
reasoning	0.081	context	0.046	association	0.034
judgment	0.081	working memory	0.044	context	0.034
focus	0.079	focus	0.04	stress	0.033
lying	0.074	perception	0.04	movement	0.032
inference	0.072	recognition	0.039	recognition	0.032
perception	0.072	mood	0.038	induction	0.03
meaning	0.071	action	0.034	integration	0.029
movement	0.06	pain	0.033	encoding	0.028
goal	0.059	sleep	0.032	thought	0.026

Cognitive Science uses broader terms, and more frequently. Frequently used terms in Cognitive Science are used much more commonly (e.g. learning, memory), and they are often high-level concepts for cognitive processes. Specific term usage in cognitive science deviates greatly from in neuroscience. This suggests that cognitive scientists and neuroscientists have different focus of study.

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